SusHi- a program to calculate the MSSM Higgs production cross section at the LHC

Hendrik Mantler

Bergische Universität Wuppertal

6th annual Workshop 'Physics at the Terascale'
in Hamburg, December 4, 2012

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Supersymmetric Higgs

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- Gluon fusion cross section within the standard model (SM) and the minimal supersymmetric standard model (MSSM) at NLO
- Different renormalization schemes for the bottom/sbottom sector
- Bottom quark annihilation at NLO within the SM
  [Harlander Ozeren Wiesemann '10]
  $\rightarrow$ can be reweighted with MSSM couplings
- Not only inclusive, but also differential cross sections:
  - Transverse momentum distribution
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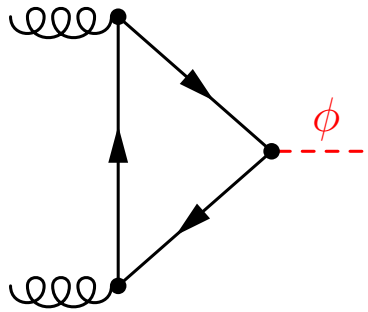
  for the MSSM: take only dominant contribution [Aglietti Bonciani Degrassi Vicini '04 '10] and reweight with MSSM coupling

Gluon fusion within the SM

LO partonic cross section:

$$\sigma_0^\phi = \frac{G_F \alpha_s^2}{288\sqrt{2}\pi} |\mathcal{A}^\phi|^2$$

$$\mathcal{A}^\phi = \sum_{q \in \{t,b\}} \left(a_q^{\phi,(0)} \right)$$



with $a_q^{\phi,(0)} = \frac{3\tau_q}{2}(1 + (1 - \tau_q^\phi) f(\tau_q^\phi))$

$$\tau_q^\phi = 4m_q^2/m_\phi^2$$

$$f(\tau) = \begin{cases} \arcsin^2 \frac{1}{\sqrt{\tau}} & \tau \geq 1 \\ -\frac{1}{4}\left(\log \frac{1+\sqrt{1-\tau}}{1-\sqrt{1-\tau}} - i\pi\right)^2 & \tau < 1 \end{cases}$$

Gluon fusion within the MSSM

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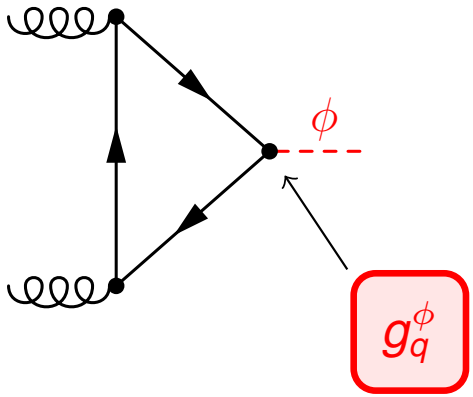

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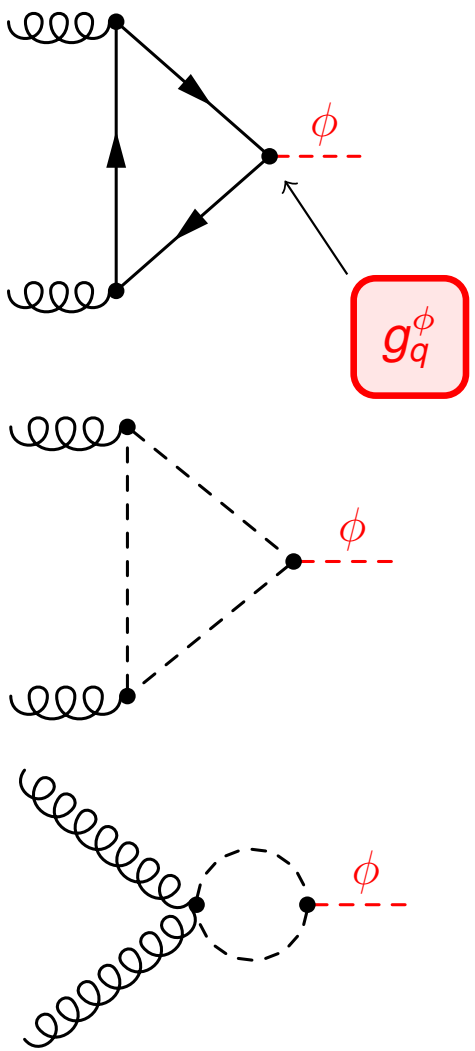
$$\mathcal{A}^\phi = \sum_{q \in \{t,b\}} \left(a_q^{\phi,(0)} + a_{\tilde{q}}^{\phi,(0)} \right)$$

with $a_q^{\phi,(0)} = g_q^\phi \frac{3\tau_q}{2}(1 + (1-\tau_q^\phi) f(\tau_q^\phi))$

$$\tilde{a}_q^{\phi,(0)} = -\frac{3\tau_q^\phi}{8} \sum_{i=1}^{2} g_{\tilde{q}ii}^\phi (1 - \tau_{\tilde{q}i}^\phi f(\tau_{\tilde{q}i}^\phi))$$

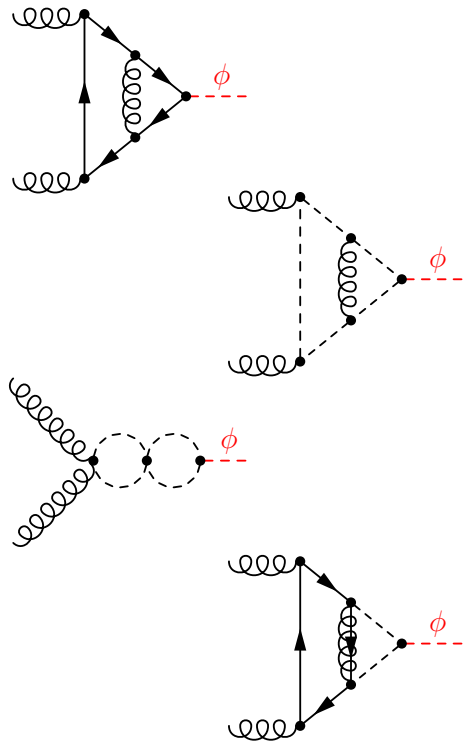
$$\tau_q^\phi = 4m_q^2/m_\phi^2, \quad \tau_{\tilde{q}i}^\phi = 4m_{\tilde{q}i}^2/m_\phi^2$$

$$f(\tau) = \begin{cases} \arcsin^2 \frac{1}{\sqrt{\tau}} & \tau \geq 1 \\ -\frac{1}{4}\left(\log \frac{1+\sqrt{1-\tau}}{1-\sqrt{1-\tau}} - i\pi \right)^2 & \tau < 1 \end{cases}$$



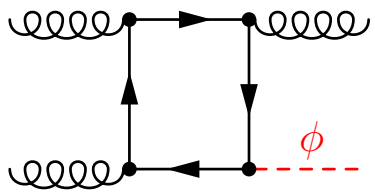
Virtual corrections

- Quark-gluon known analytically (at higher orders)
  [Spira Djouadi Graudenz Zerwas '95; Harlander Kant '05]
- Squark-gluon/squark known analytically
  [Anastasiou Beerli Bucherer Daleo Kunszt '06; Aglietti Bonciani Degrassi Vicini '06; Mühlleitner Spira '06]
- Quark-squark-gluino semi-analytically known, but no public code
  [Anastasiou Beerli Daleo '08; Mühlleitner Rzehak Spira '10]

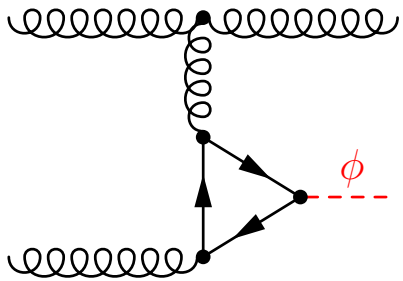


  - Taylor expansion in the Higgs mass: $m_\phi \ll m_q, m_{\tilde{q}_1}, m_{\tilde{q}_2}, m_{\tilde{g}}$
    [Harlander Steinhauser '03 '04 + Hofmann '05; Degrassi Slavich '08]
    $\longrightarrow$ top-stop-gluino
  - Expansion in SUSY masses: $m_\phi, m_q \ll m_{\tilde{q}_1}, m_{\tilde{q}_2}, m_{\tilde{g}}$
    for $m_{\tilde{q}_1} = m_{\tilde{q}_2} = m_{\tilde{g}}$ [Harlander Hofmann Mantler '10]
    for arbitrary SUSY masses [Degrassi Slavich '10 + Di Vita '11 '12]
    $\longrightarrow$ bottom-sbottom-gluino

Real corrections



- Quark
  known analytically
  [Spira Djouadi Graudenz Zerwas '95]



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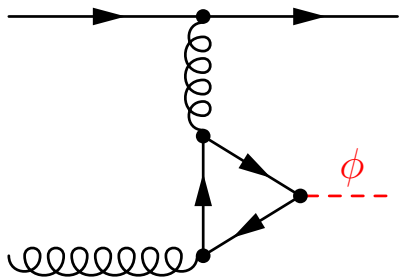
  [Mühlleitner Spira '06; Bonciani Degrassi Vicini '07]



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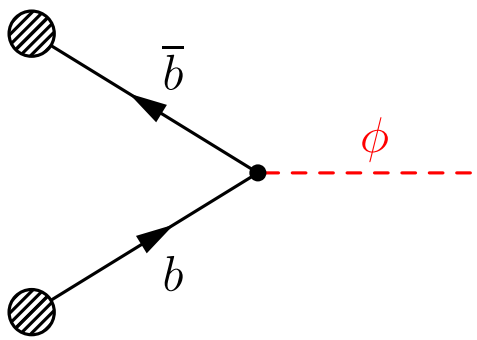

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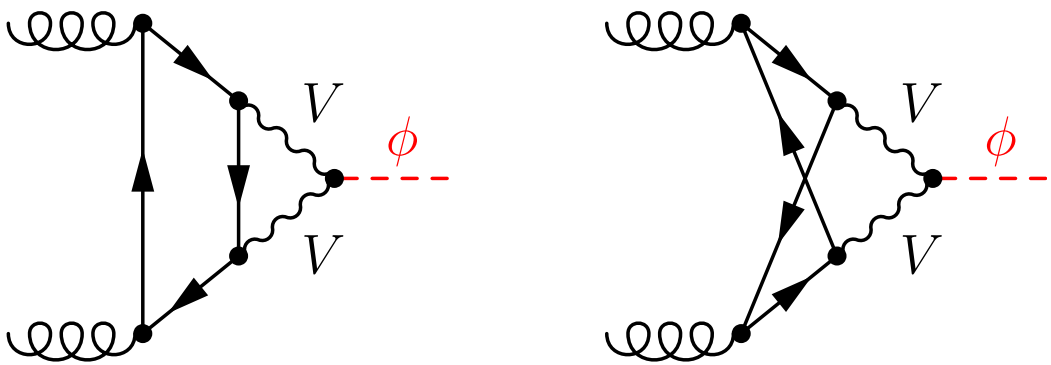
Diagrams including only light quarks:



- Electroweak corrections at NLO in the SM from `EWgint`
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Results

Results

Fitting the parameters of the MSSM to the data:

[P. Bechtle, S. Heinemeyer, O. Stål, T. Stefaniak, G. Weiglein, L. Zeune]

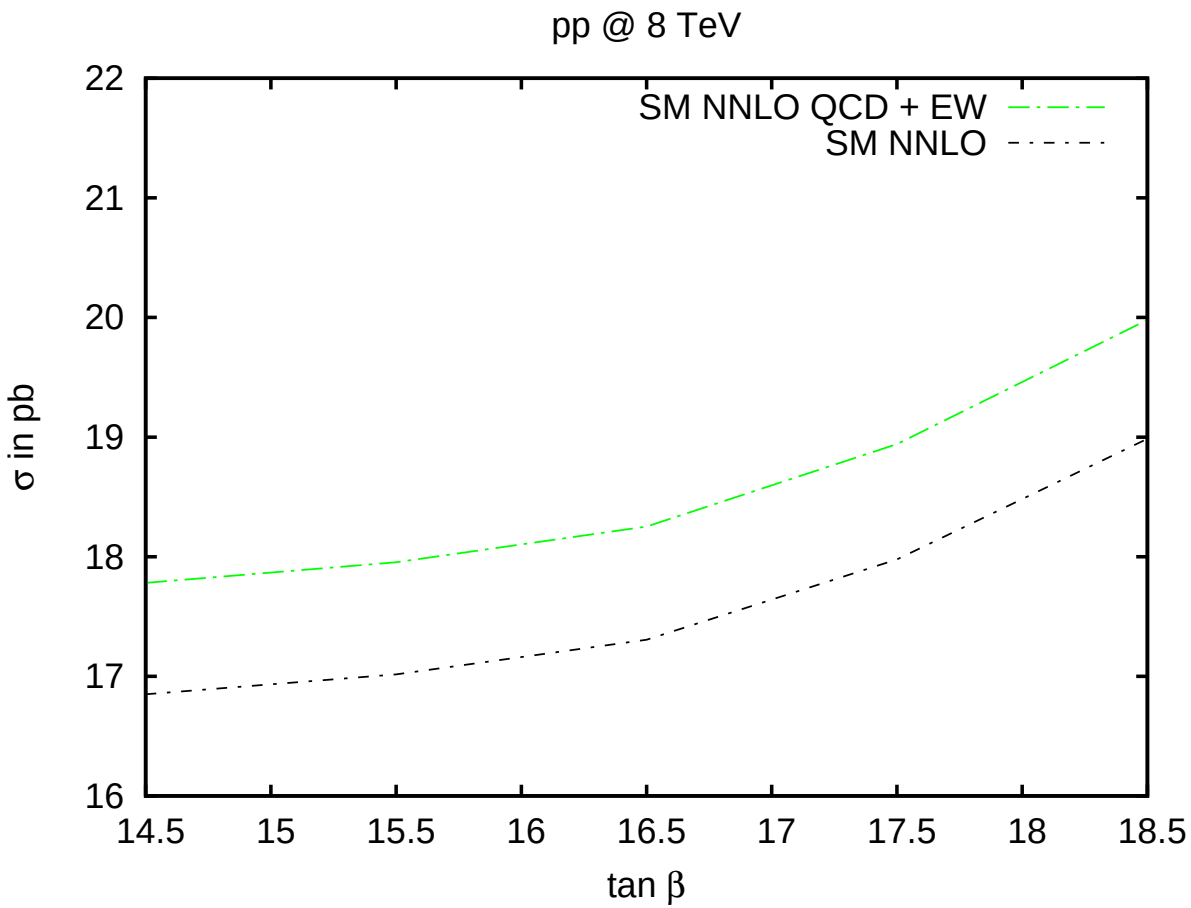
Parameter	Light Higgs case Best fit			Heavy Higgs case Best fit		
M_A [GeV]	300	669	860	120.5	124.2	128.0
$\tan\beta$	15	16.5	26	9.7	9.8	10.8
μ [GeV]	1900	2640	(3000)	1899	2120	2350
$M_{\tilde{q}_3}$ [GeV]	450	1100	(1500)	580	670	740
$M_{\tilde{l}_3}$ [GeV]	250	285	(1500)	(200)	323	(1500)
A_f [GeV]	1100	2569	3600	1450	1668	1840
M_2 [GeV]	(200)	201	450	(200)	304	370
M_h [GeV]	122.2	126.1	127.1	63.0	65.3	72.0
M_H [GeV]	280	665	860	123.9	125.8	126.4
$M_{H^\pm}$ [GeV]	310	673	860	136.5	138.8	141.5

Table 6: Best fit parameter values (in the respective middle column) and ranges for $\Delta\chi^2_{h,H} < 1$. Values in parentheses indicate that the limit of the scan range has been reached.

- Vary tan β within the given range
- Fix other parameters to the best fit values

Results

Total cross section:



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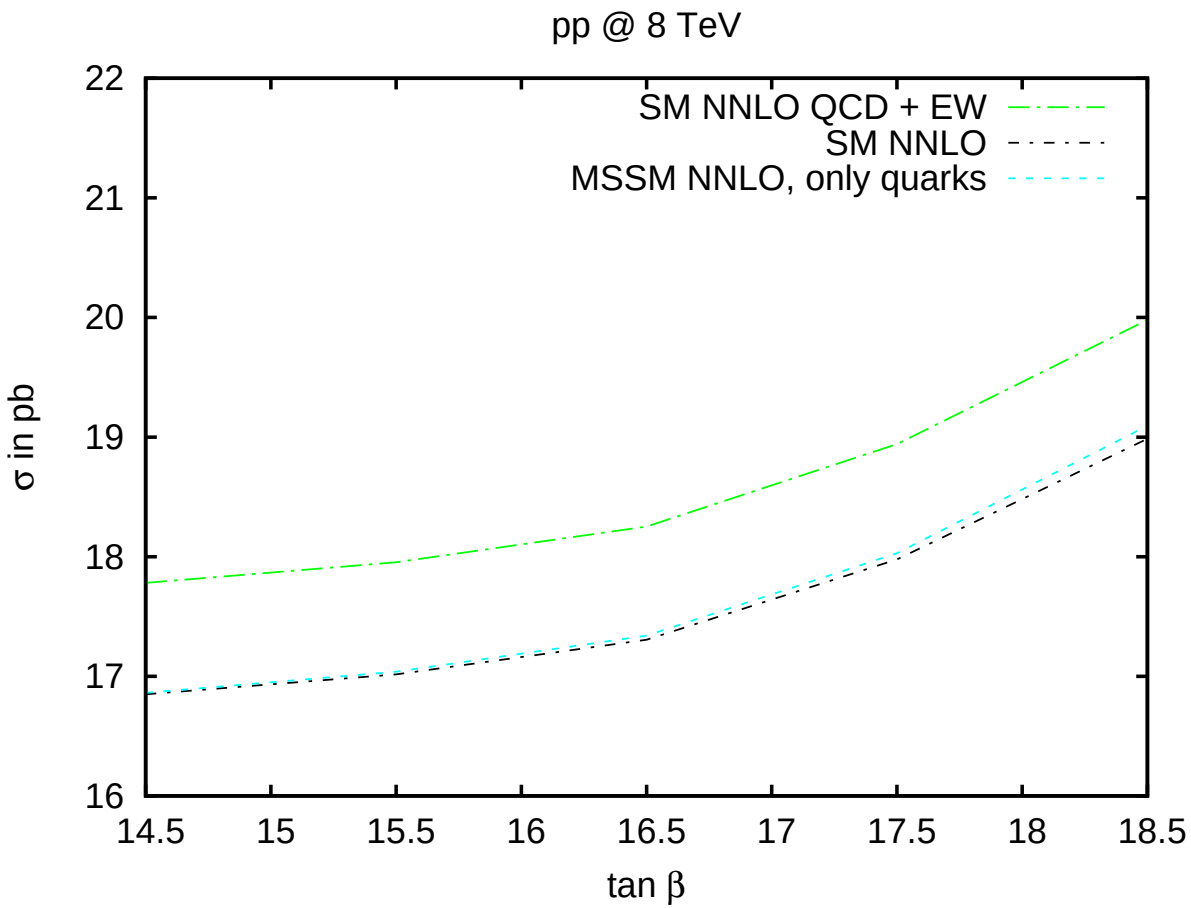

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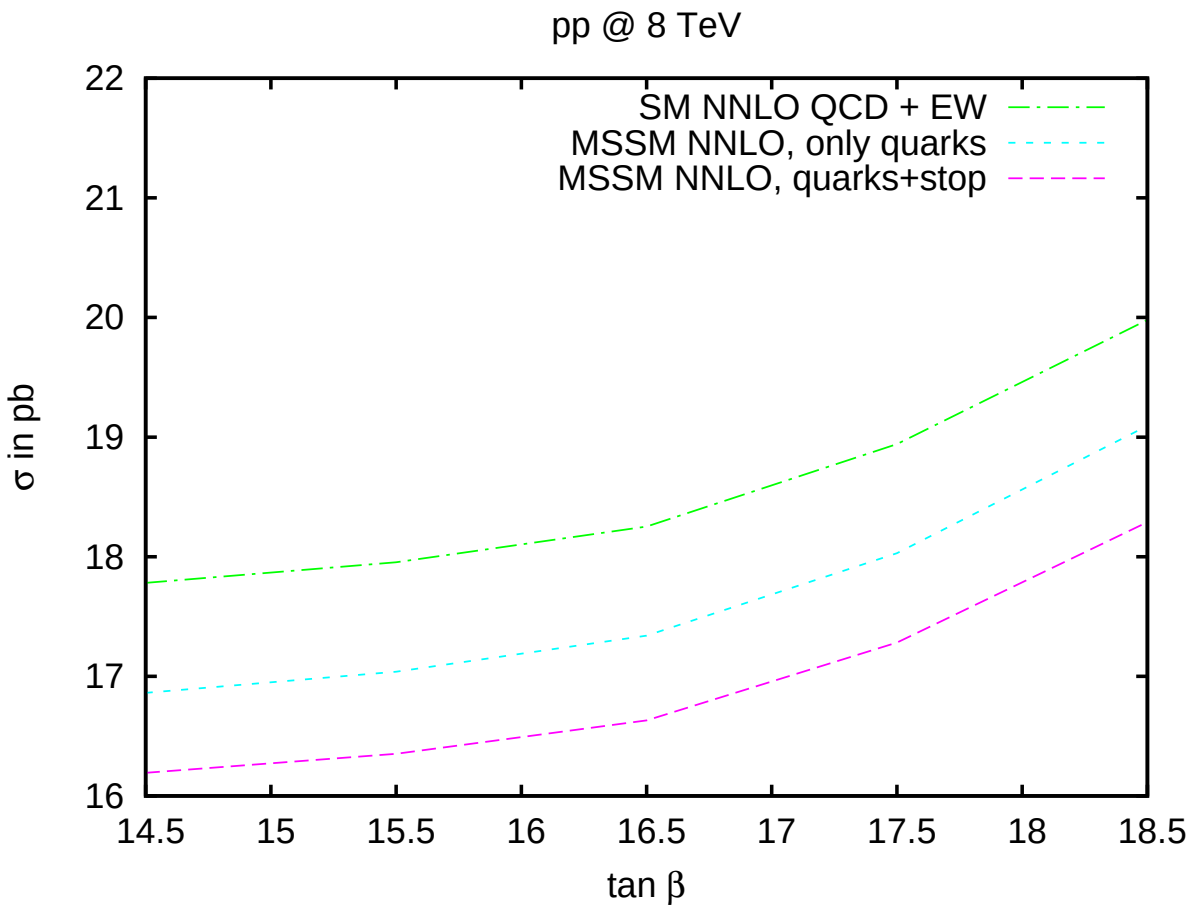

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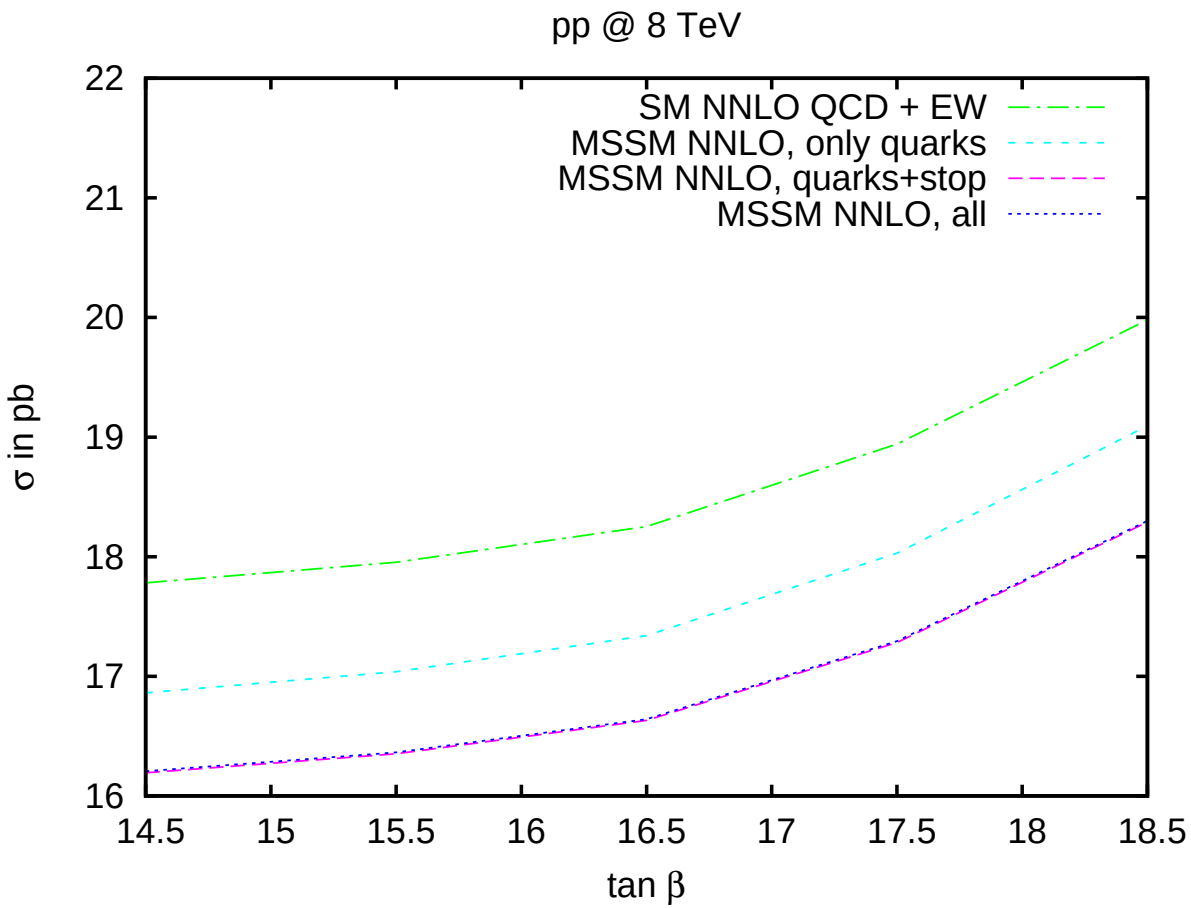

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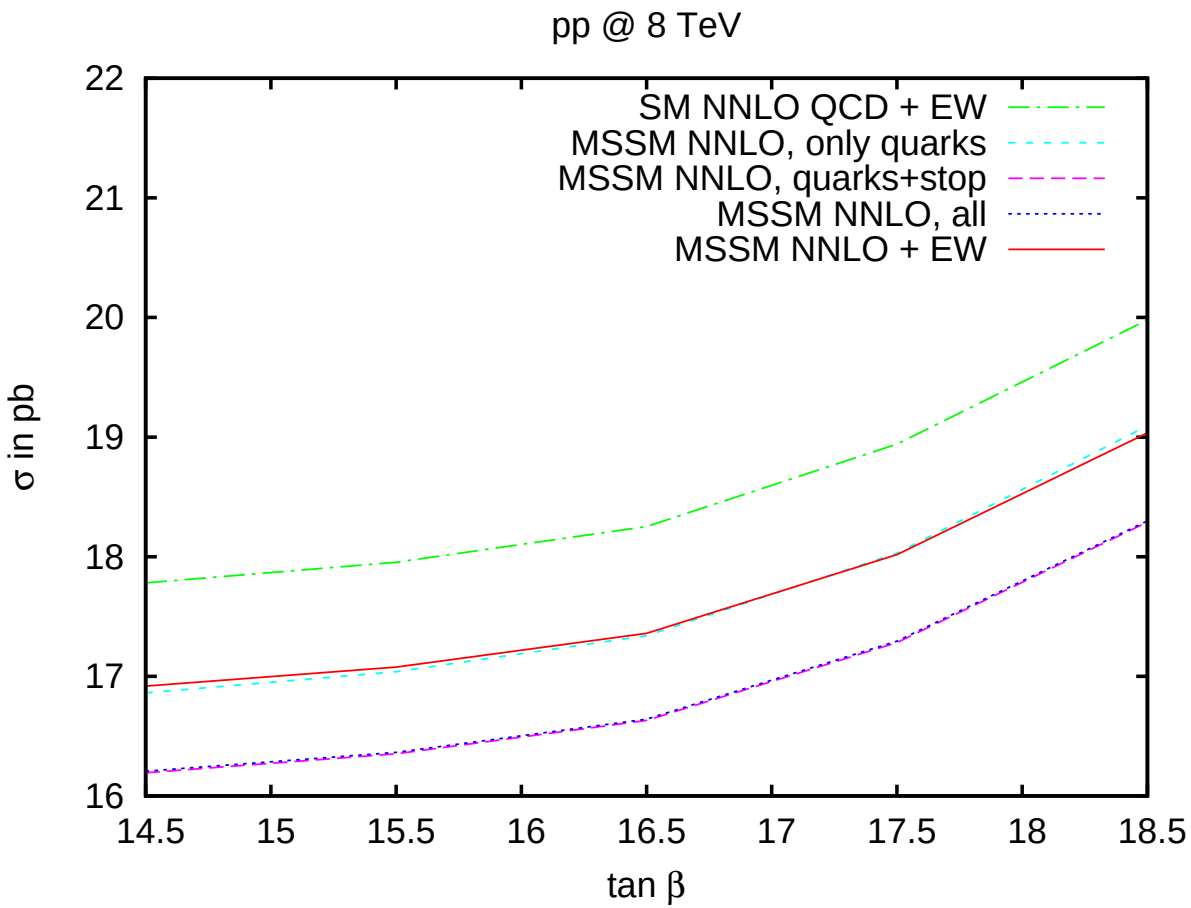

Conclusion

- `SusHi` can calculate the Higgs production cross section within the MSSM including the squark diagrams in gluon fusion
- For a SM-like Higgs, the squark diagrams and the electroweak corrections contribute to about 4% each, but with different sign
- We produce new numbers for the YR 3
- `SusHi` will be published soon

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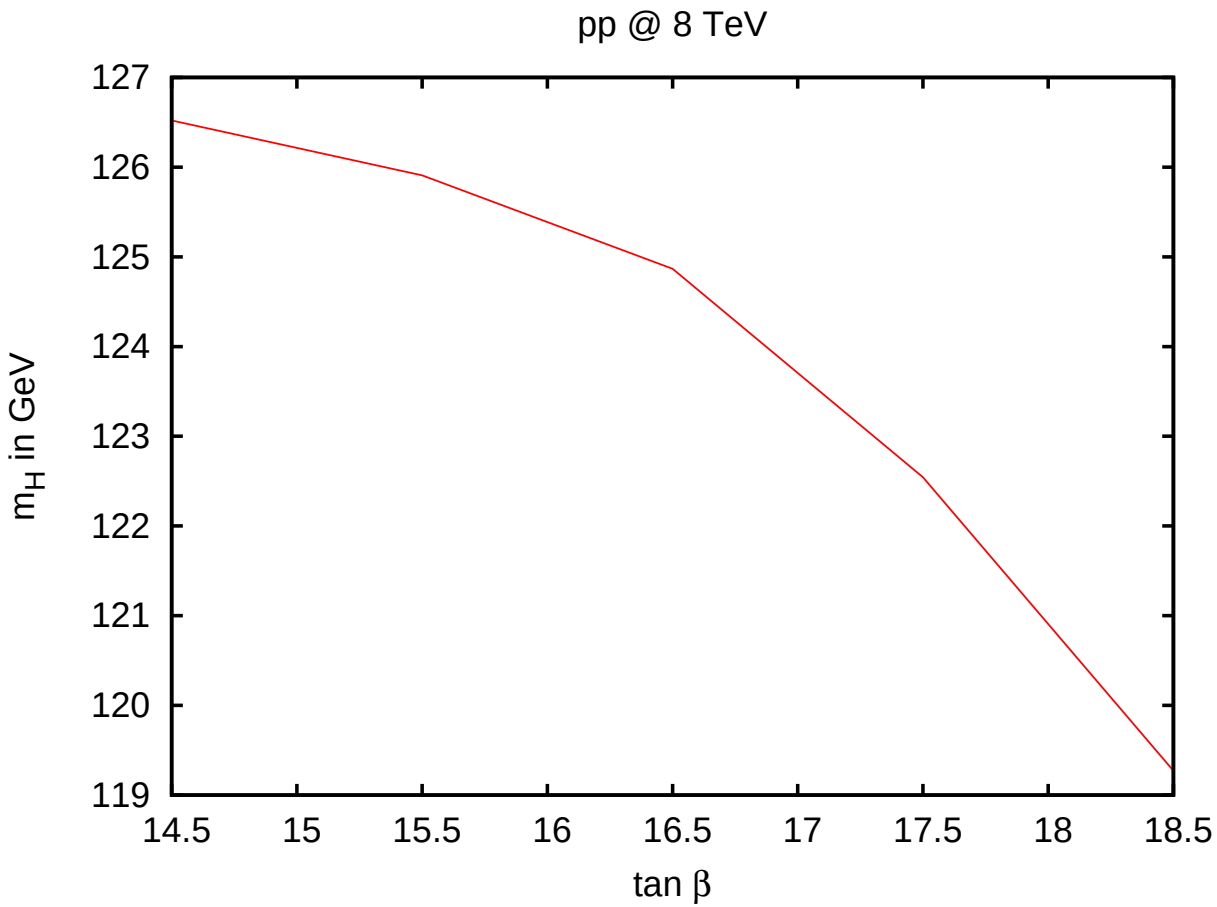
Thanks for your attention!

Backup

Results

Higgs mass dependence:



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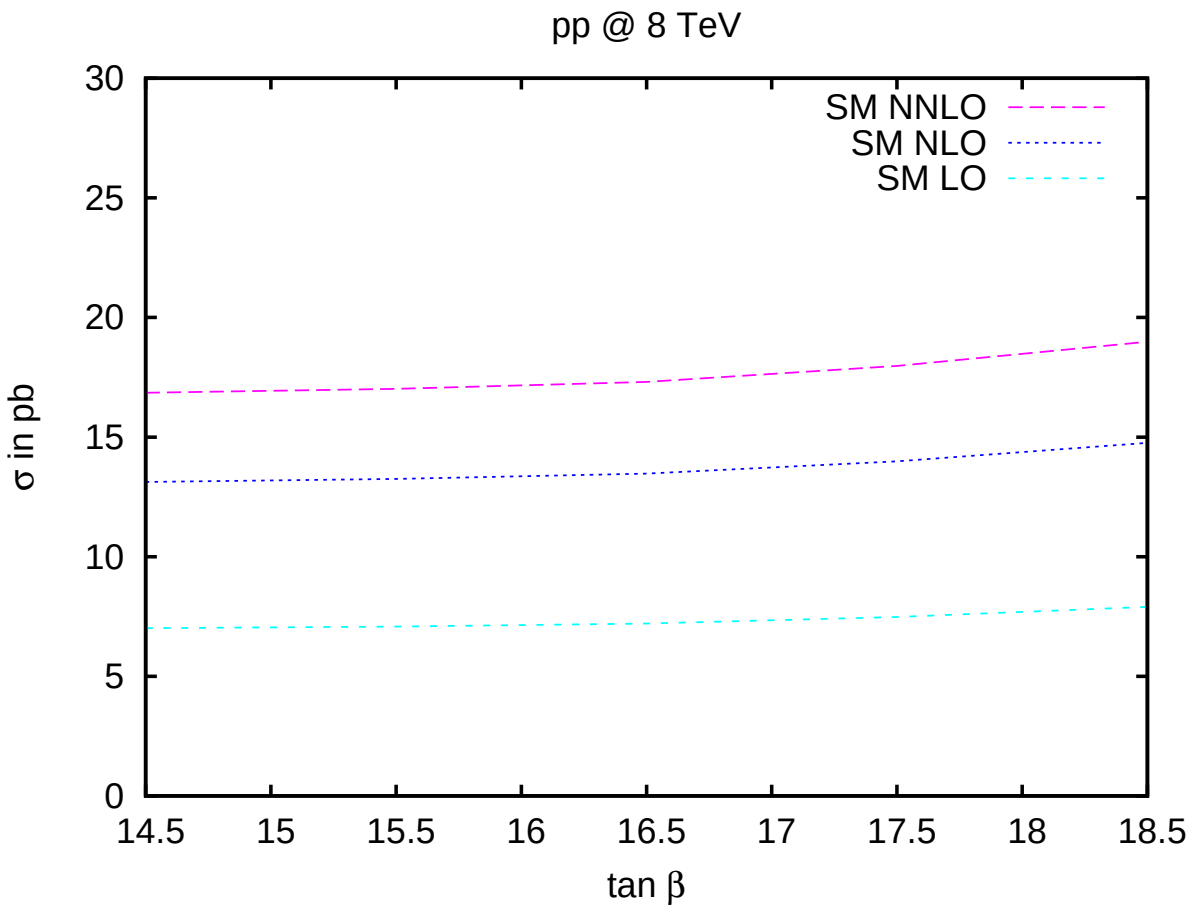

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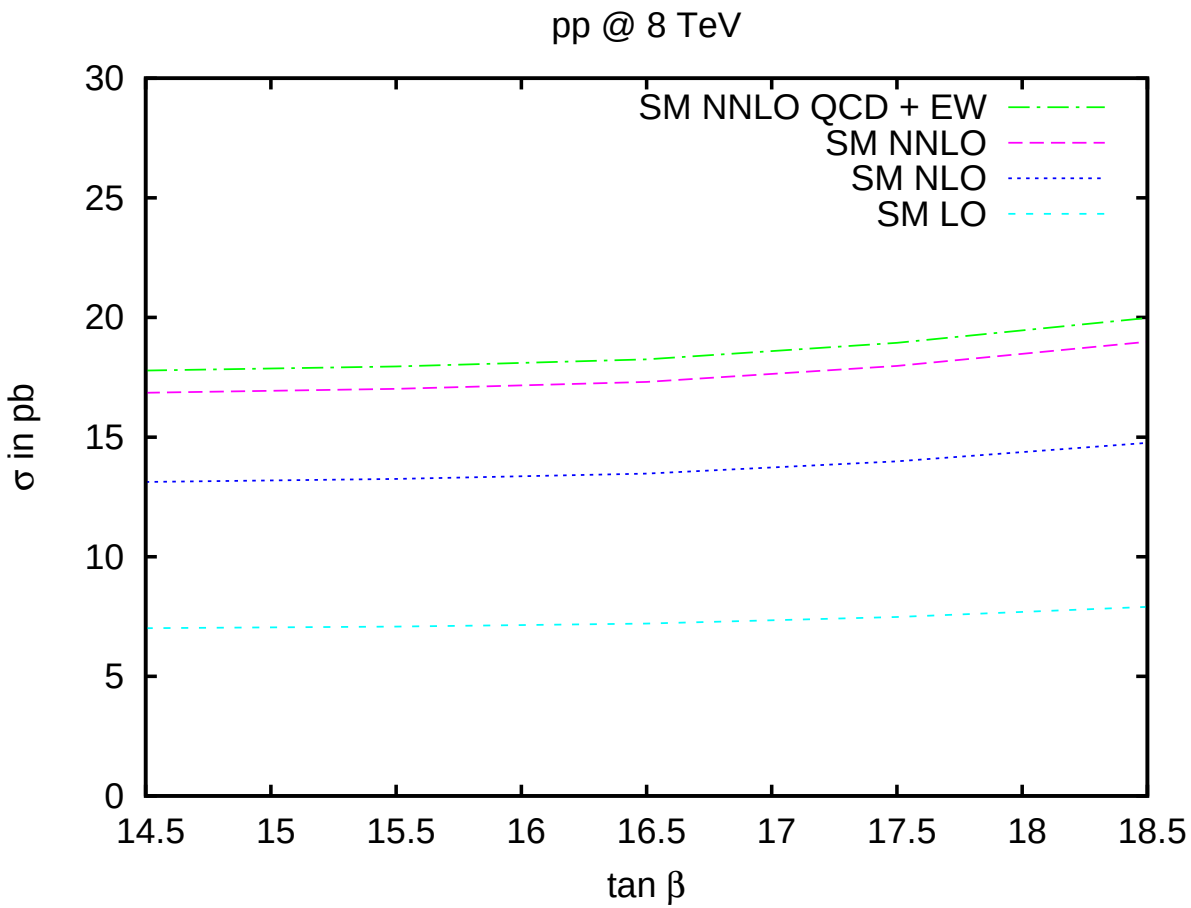

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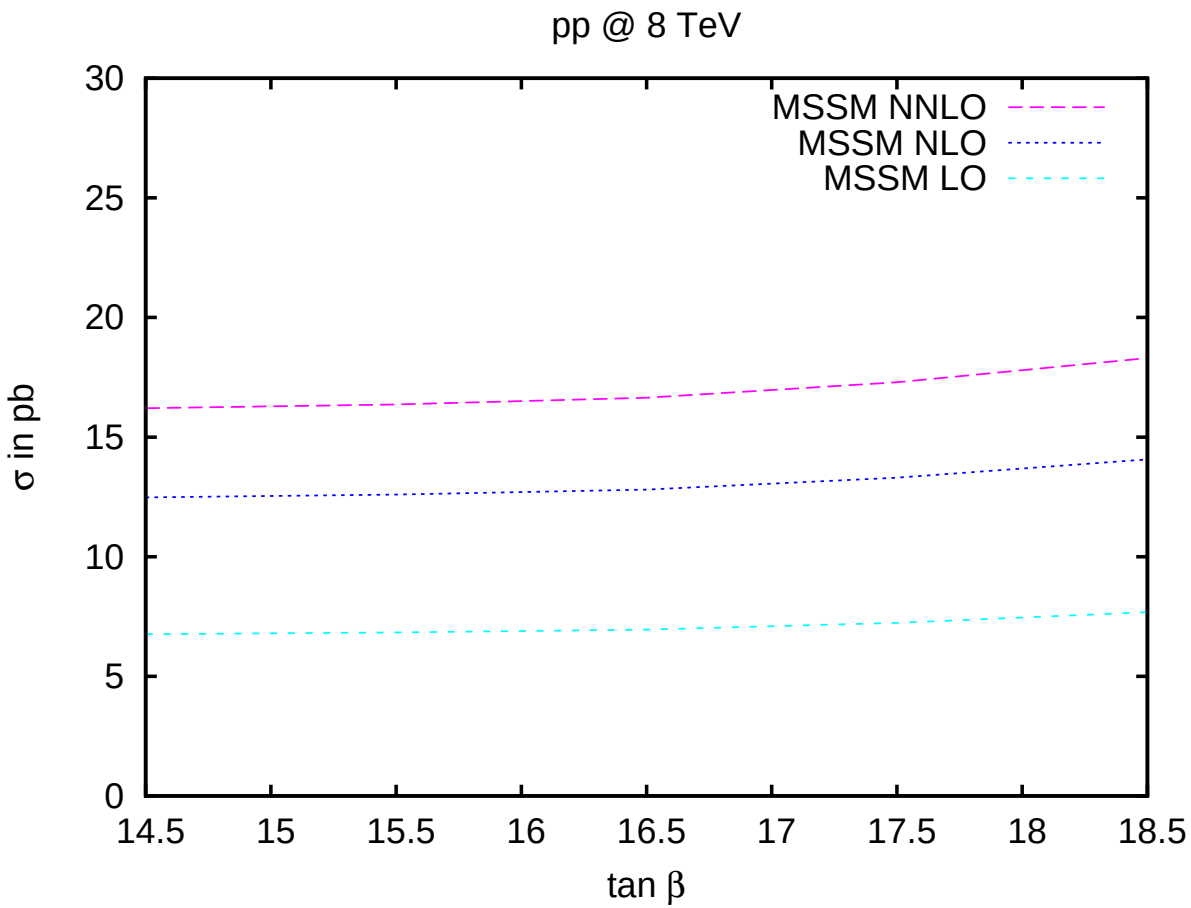

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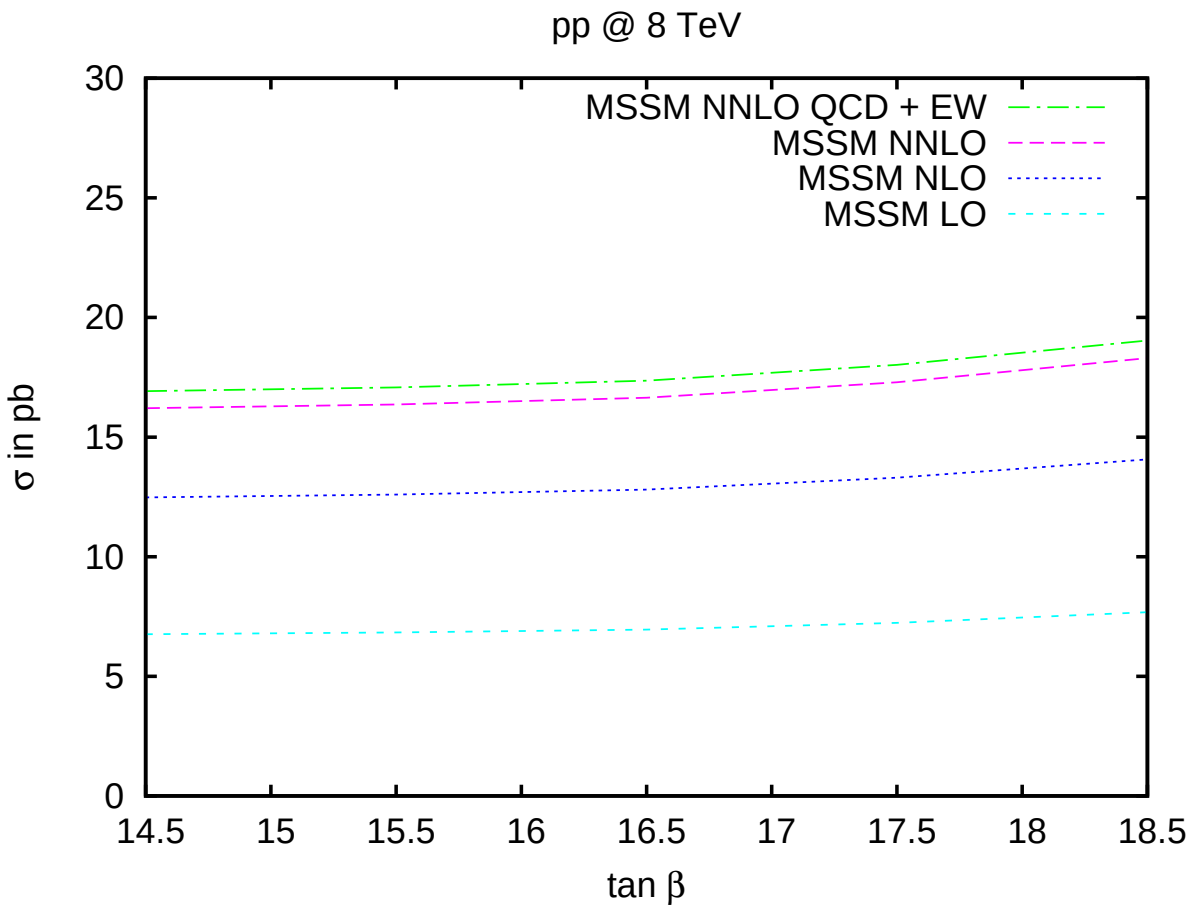


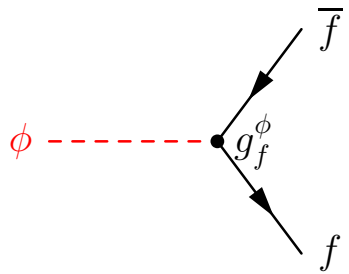
Quark-Higgs-Coupling

The minimal supersymmetric standard model (MSSM) contains two Higgs doublets, resulting in 3 neutral Higgs bosons $\phi = \{h, H, A\}$. The coupling constants to the quarks are altered.

Relative strength of the Higgs boson couplings g_f^ϕ to the quarks (with respect to the SM Higgs boson couplings):

$$g_u^h = \frac{\cos\alpha}{\sin\beta} \qquad g_u^H = \frac{\sin\alpha}{\sin\beta} \qquad g_u^A = \frac{1}{\tan\beta}$$

$$g_d^h = -\frac{\sin\alpha}{\cos\beta} \qquad g_d^H = \frac{\cos\alpha}{\cos\beta} \qquad g_d^A = \tan\beta$$



where α is the mixing angle in the Higgs sector and $\tan\beta = v_u/v_d$ the ratio of the vacuum expectation values.

In the MSSM Higgs couplings to the *b*-quark are enhanced by $\tan\beta$.

Formulas

$$\sigma^{\mathrm{SM},(\mathrm{MSSM})}_{gg\phi} = \sigma^{\mathrm{SM},(\mathrm{MSSM})}_{gg\phi,\mathrm{NLO}} + (g^{\phi}_{t})^2 \left[(1+\delta_{\mathrm{EW}})\hat{\sigma}^{\mathrm{SM},t}_{gg\varphi,\mathrm{NNLO}} - \hat{\sigma}^{\mathrm{SM},t}_{gg\varphi,\mathrm{NLO}}\right] \tag{1}$$

$$\sigma^{\mathrm{SM},(\mathrm{MSSM})}_{gg\phi} = \sigma^{\mathrm{SM},(\mathrm{MSSM})}_{gg\phi,\mathrm{NLO}} + (g^{\phi}_{t})^2 \left[\delta_{\mathrm{EW}}\hat{\sigma}^{\mathrm{SM},t}_{gg\varphi,\mathrm{NLO}}\right] \tag{2}$$

$$g^{h}_{V} = \sin(\beta-\alpha), \quad g^{A}_{V} = 0, \quad g^{H}_{V} = \cos(\beta-\alpha) \tag{3}$$

$$\sigma^{\mathrm{SM},(\mathrm{MSSM})}_{gg\phi} = \sigma^{\mathrm{SM},(\mathrm{MSSM})}_{gg\phi,\mathrm{NLO}}(1+\delta^{lf}_{\mathrm{EW}}) + (g^{\phi}_{t})^2 \left[\hat{\sigma}^{\mathrm{SM},t}_{gg\varphi,\mathrm{NNLO}} - \hat{\sigma}^{\mathrm{SM},t}_{gg\varphi,\mathrm{NLO}}\right] \tag{4}$$